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Ebrahimi Afrouzi et al.

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(54) WHEEL SUSPENSION SYSTEM

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(Continued)

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B60G 3/26 (2006.01)
B60G 21/05 (2006.01)
B60G 3/14 (2006.01)

(52) **U.S. Cl.**
CPC ***B60G 3/26*** (2013.01); ***B60G 3/145*** (2013.01); ***B60G 21/051*** (2013.01); *A47L 2201/00* (2013.01); *B60G 2200/13* (2013.01); *B60G 2202/122* (2013.01); *B60G 2202/13* (2013.01); *B60G 2202/42* (2013.01); *B60G 2204/1244* (2013.01)

(58) **Field of Classification Search**
CPC B60G 3/26; B60G 21/051; B60G 2204/1244; B60G 2202/13; B60G 2202/42; B60G 3/145; B60G 2200/13; B60G 2202/122; A47L 2201/00; A47L 2201/04

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,537,420 A 8/1985 Ito
5,036,941 A * 8/1991 Denzin B60G 3/00 180/252

(Continued)

OTHER PUBLICATIONS

The URANUS Mobile Robot, Mike Blackwell, Mobile Robot Lab, The Robotics Institute Carnegie Mellon University, Pittsburgh, PA, 1S213, Sep. 1990 (attached).

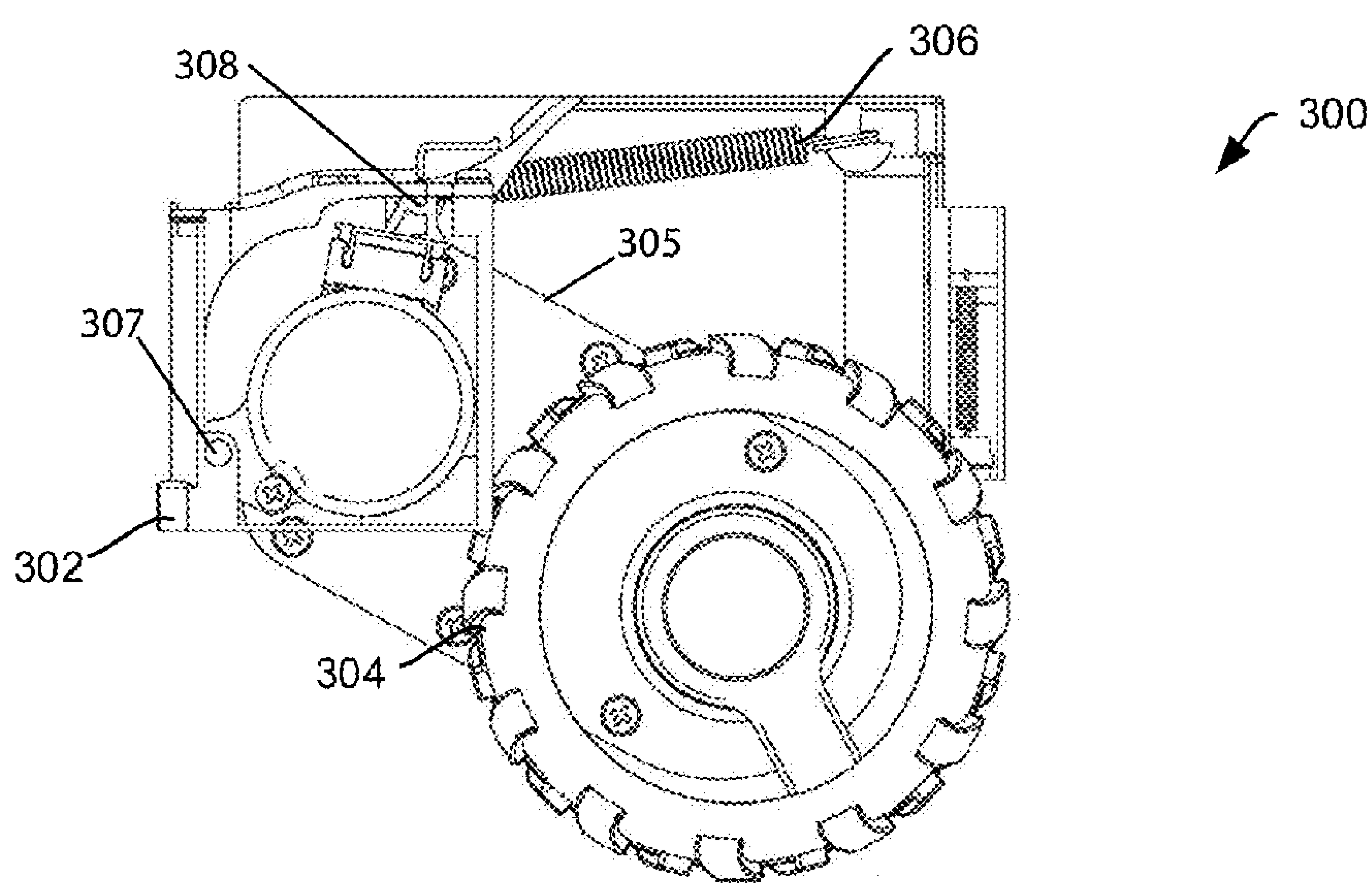
(Continued)

Primary Examiner — Paul N Dickson
Assistant Examiner — Timothy Wilhelm

(57) **ABSTRACT**

Provided is a robotic device including: a body; an electronic computing device housed within the body; and at least two wheel suspension systems coupled with the body including: a first suspension system including: a frame; a rotating arm pivotally coupled to the frame on a first end and coupled to a wheel on a second end; and an extension spring coupled with the rotating arm on a third end and the frame on a fourth end, wherein the extension spring is extended when the wheel is retracted; and a second suspension system including: a base slidingly coupled with the frame; a plurality of vertically positioned extension springs coupled with the frame on a fifth end and the base on a sixth end; at least one set of paired magnets, with at least one magnet affixed to the frame and paired to at least one magnet affixed to the base.

28 Claims, 7 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/620,352, filed on Jan. 22, 2018, provisional application No. 62/617,589, filed on Jan. 15, 2018, provisional application No. 62/540,189, filed on Aug. 2, 2017.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,697,633	A	12/1997	Lee	
5,924,712	A	7/1999	Pierce	
6,581,239	B1 *	6/2003	Dyson	A47L 5/34 15/340.3
7,249,640	B2 *	7/2007	Horchler	B62D 57/022 180/7.1
7,418,762	B2 *	9/2008	Arai	A47L 5/28 15/319
7,441,298	B2 *	10/2008	Svendsen	A47L 5/30 15/49.1
7,581,282	B2 *	9/2009	Woo	A47L 9/009 15/319
7,975,790	B2 *	7/2011	Kim	B60G 3/01 180/65.51
8,417,383	B2 *	4/2013	Ozick	G05D 1/0231 700/245
8,515,577	B2 *	8/2013	Wang	B25J 9/1689 700/247
9,033,079	B2 *	5/2015	Shin	B25J 5/007 180/65.6
9,259,129	B2 *	2/2016	Jang	A47L 9/2805
9,259,159	B2	2/2016	Jang	
9,317,038	B2 *	4/2016	Ozick	A47L 9/009
9,326,654	B2 *	5/2016	Doughty	A47L 9/0477
9,335,767	B2 *	5/2016	Jang	G05D 1/0227
9,364,129	B2 *	6/2016	Weis	A47L 11/32
9,480,380	B2 *	11/2016	Yoo	A47L 11/4011
9,661,971	B2 *	5/2017	Riehl	A47L 9/009
9,687,132	B2 *	6/2017	Schlischka	A47L 11/4061
9,758,006	B2 *	9/2017	Jeong	B60G 17/0195
9,883,778	B2 *	2/2018	Vanderstegen-Drake	A47L 9/009
9,908,432	B2 *	3/2018	Park	B60L 15/20
9,936,844	B2 *	4/2018	Nakamura	A47L 9/009
2006/0005344	A1 *	1/2006	Uehigashi	A47L 9/009 15/319
2008/0282494	A1 *	11/2008	Won	A47L 5/30 15/319
2010/0243344	A1 *	9/2010	Wyrobek	B25J 5/007 180/21
2013/0054022	A1 *	2/2013	Jang	A47L 9/2805 700/245
2015/0150429	A1 *	6/2015	Yoo	A47L 11/4011 173/1
2016/0259336	A1 *	9/2016	Lee	B60G 17/016

OTHER PUBLICATIONS

International Application No. PCT/US18/44357 ISR and WO.

* cited by examiner

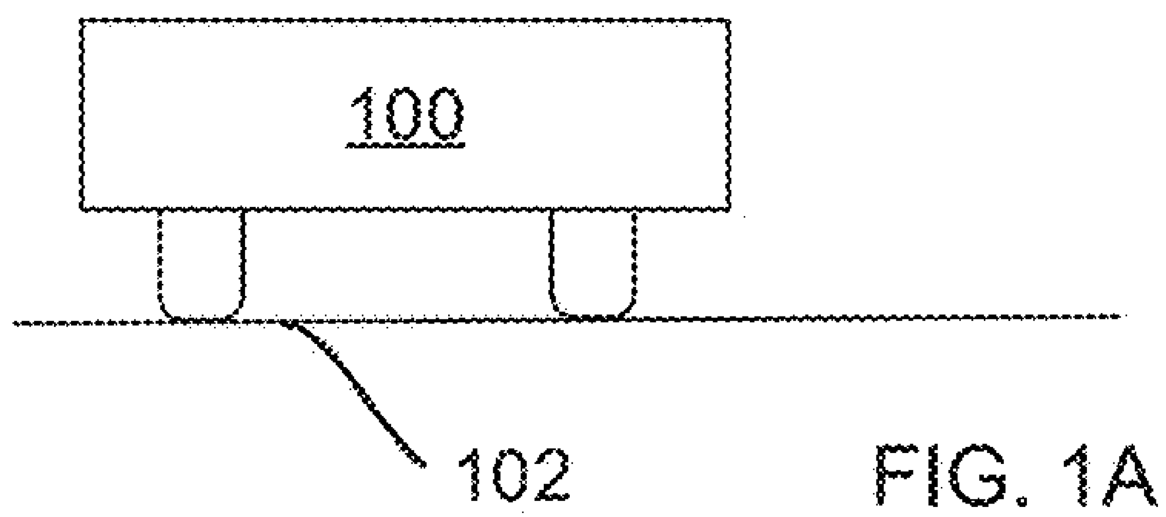


FIG. 1A
(PRIOR ART)

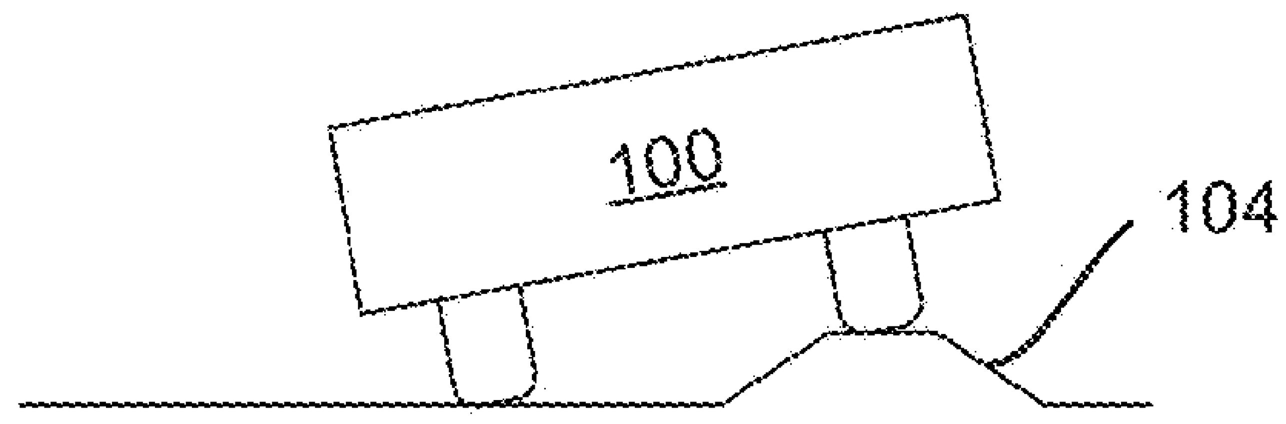


FIG. 1B
(PRIOR ART)

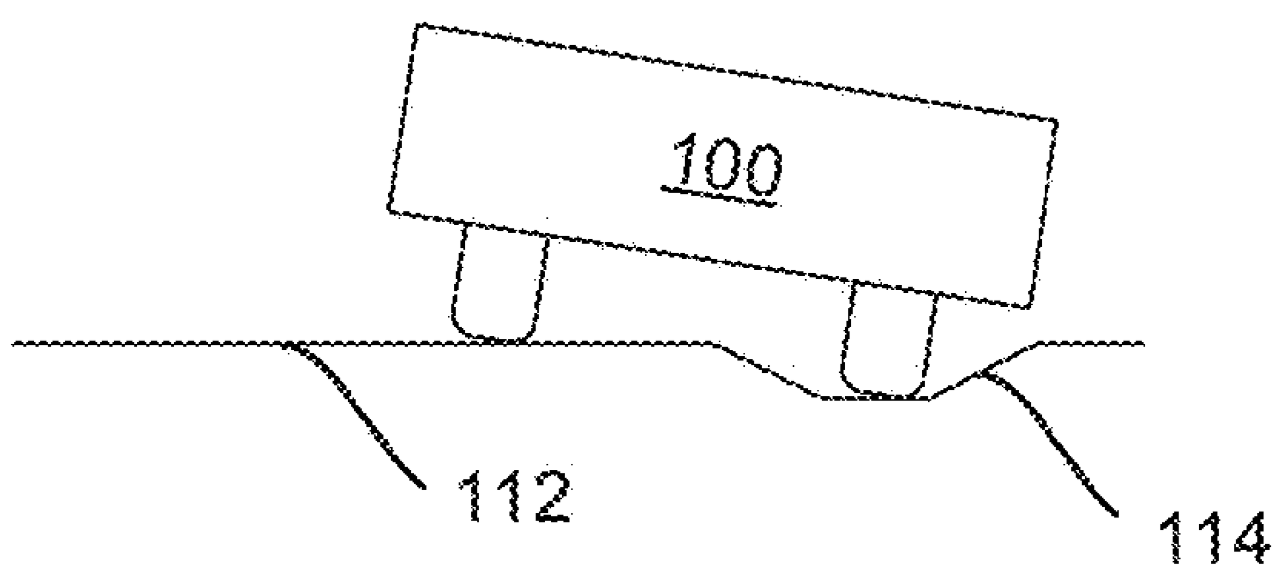


FIG. 1C
(PRIOR ART)

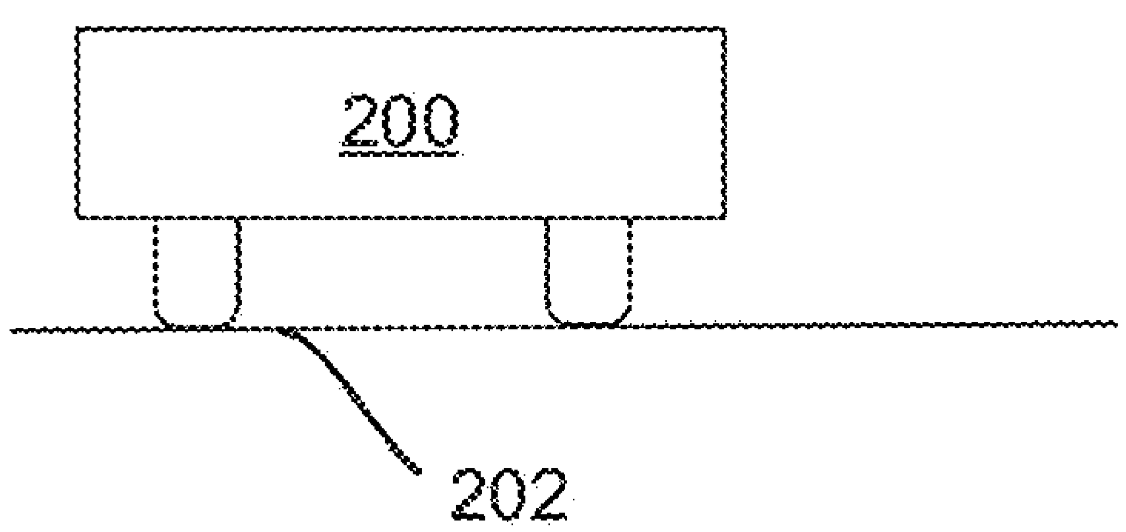


FIG. 2A
(PRIOR ART)

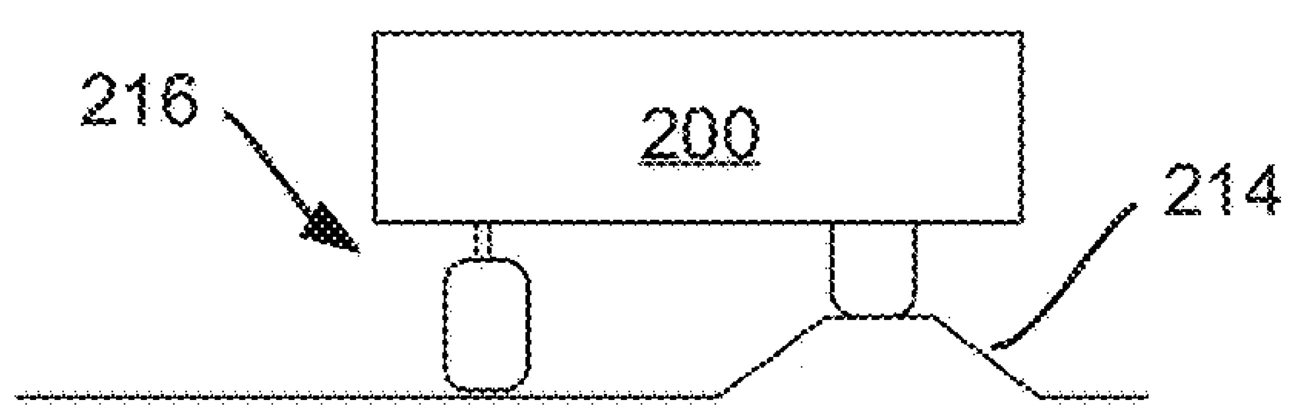


FIG. 2B
(PRIOR ART)

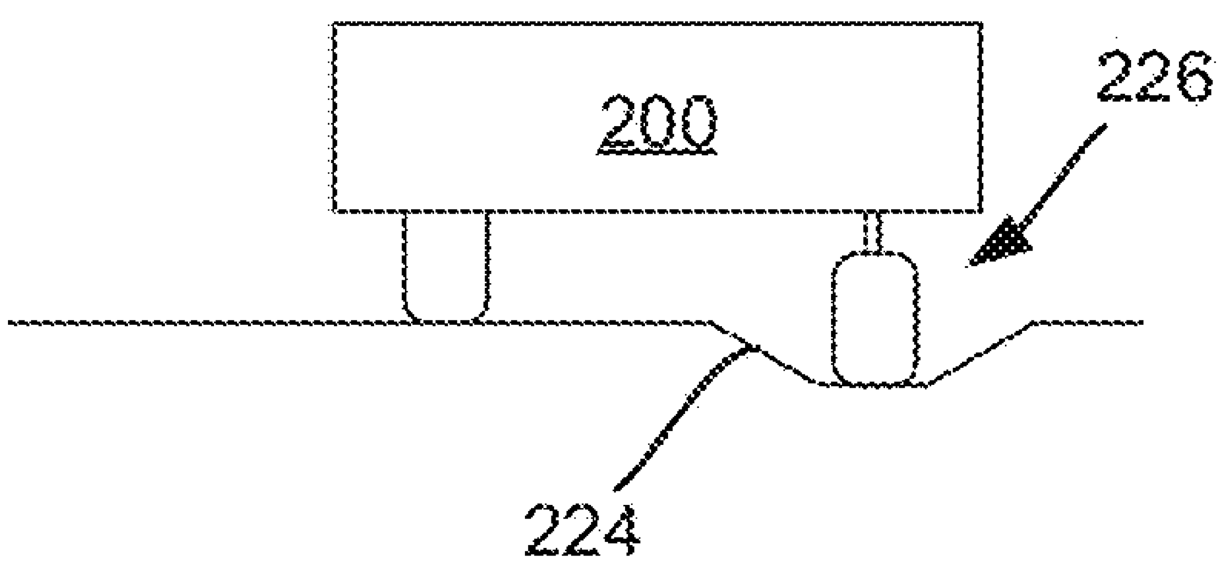


FIG. 2C
(PRIOR ART)

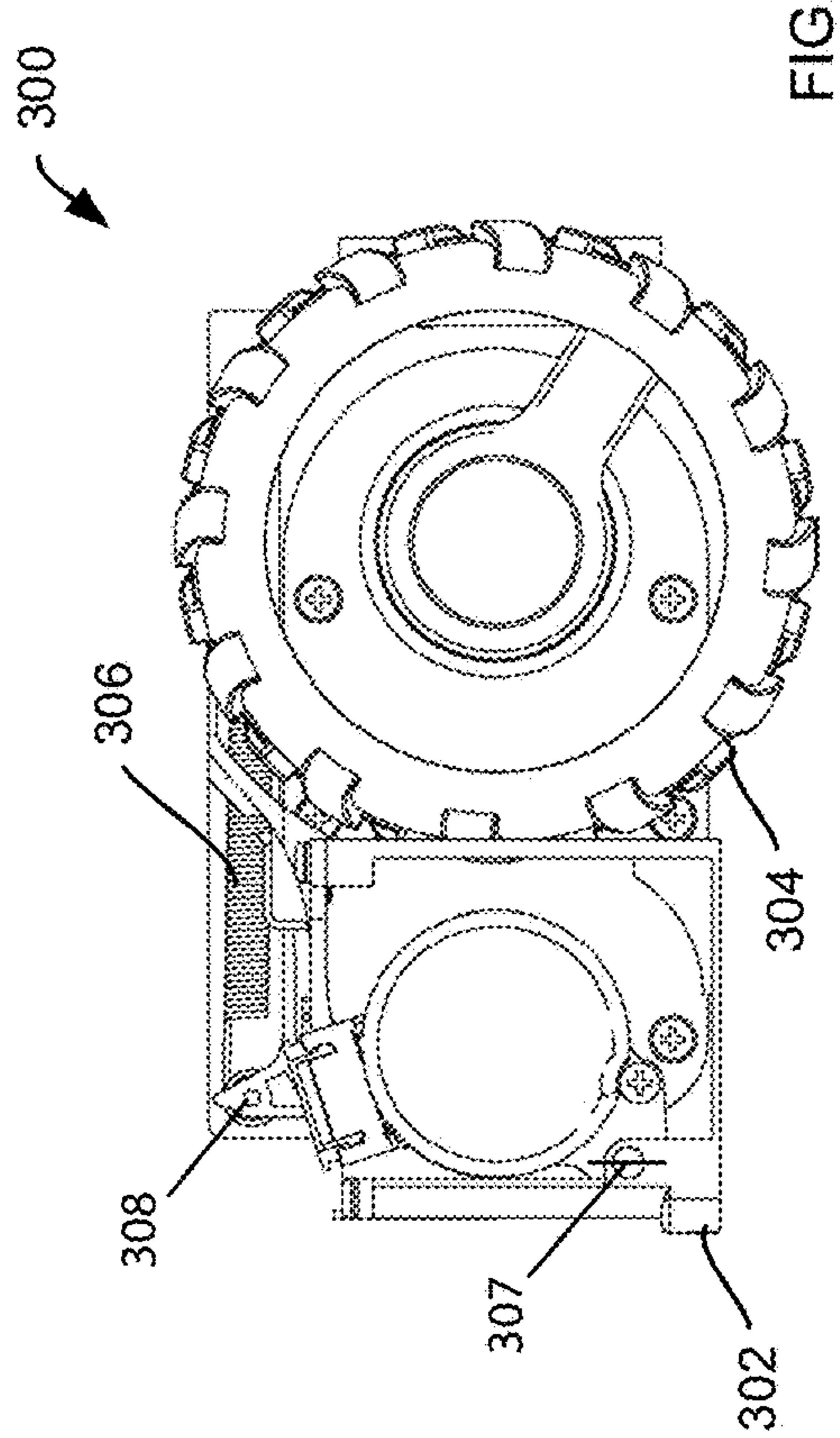


FIG. 3B

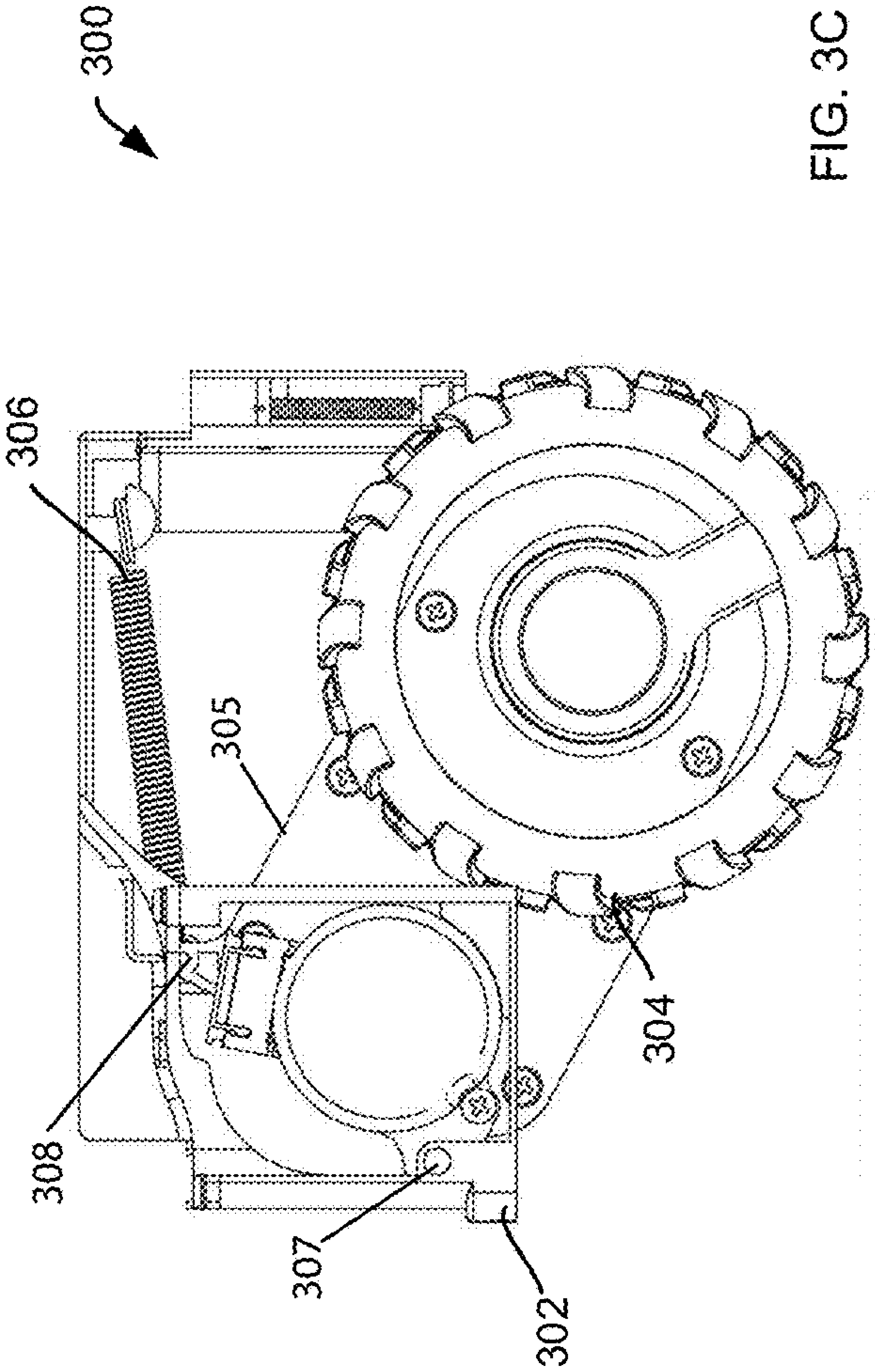


FIG. 3C

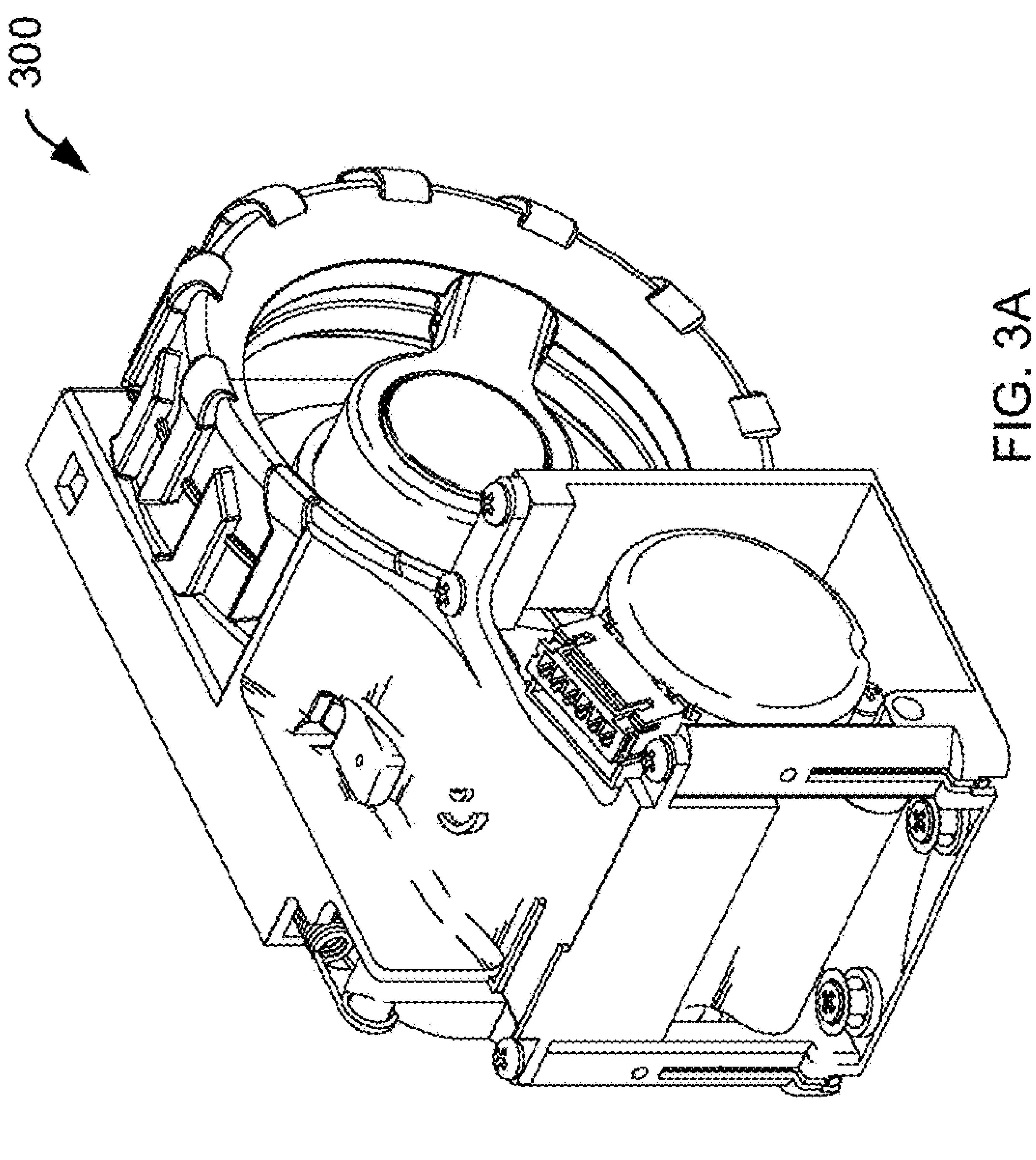
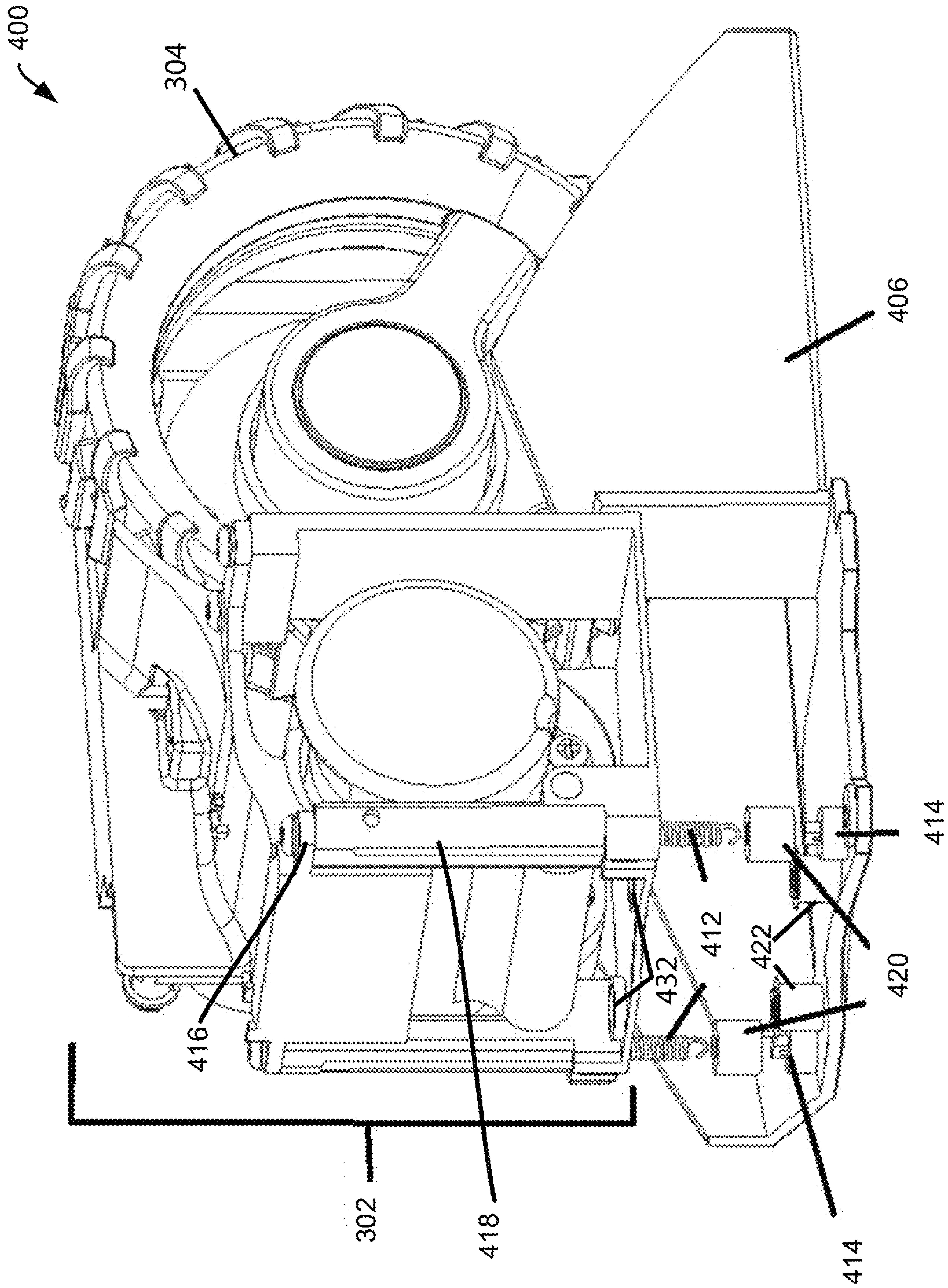


FIG. 3A

FIG. 4



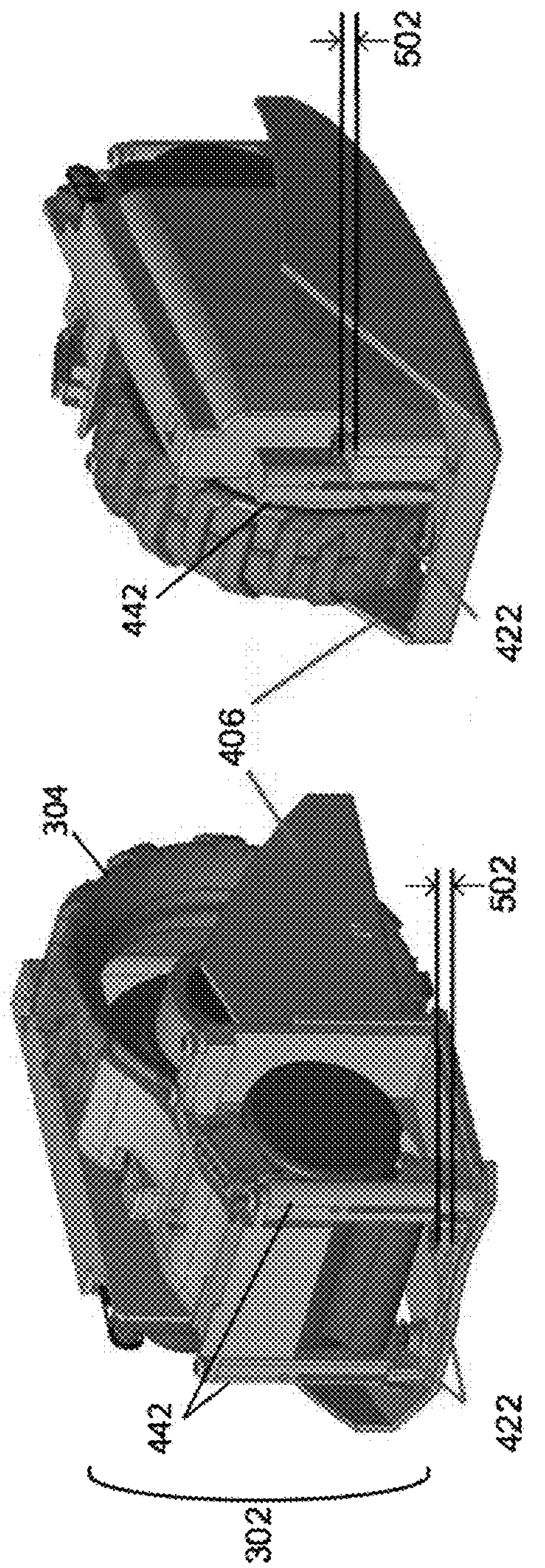


FIG. 5A

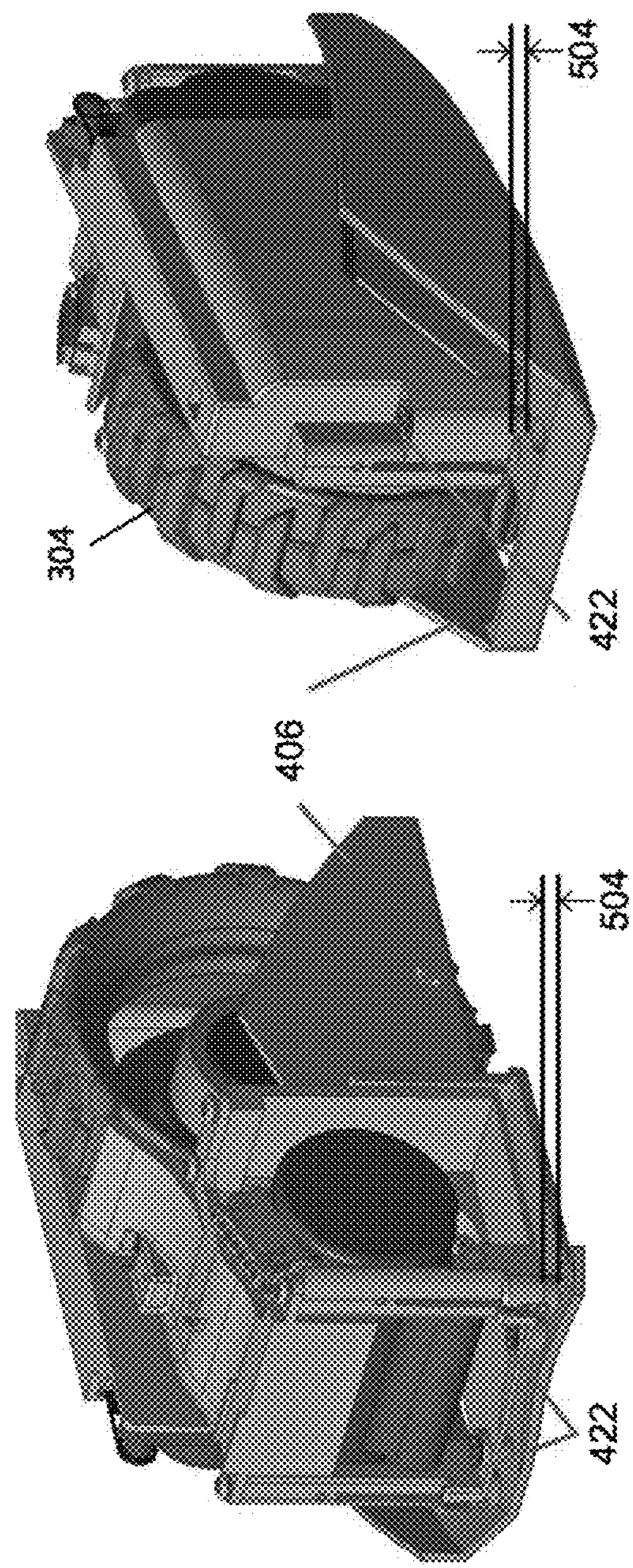


FIG. 5B

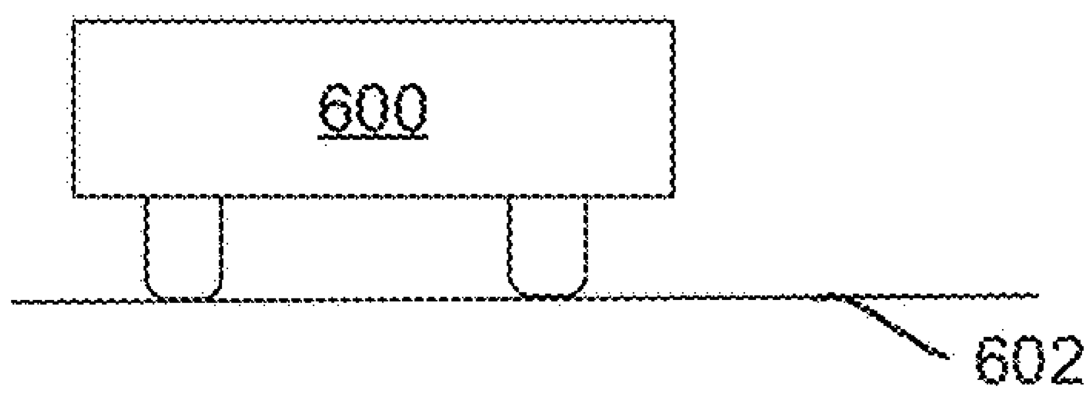


FIG. 6A

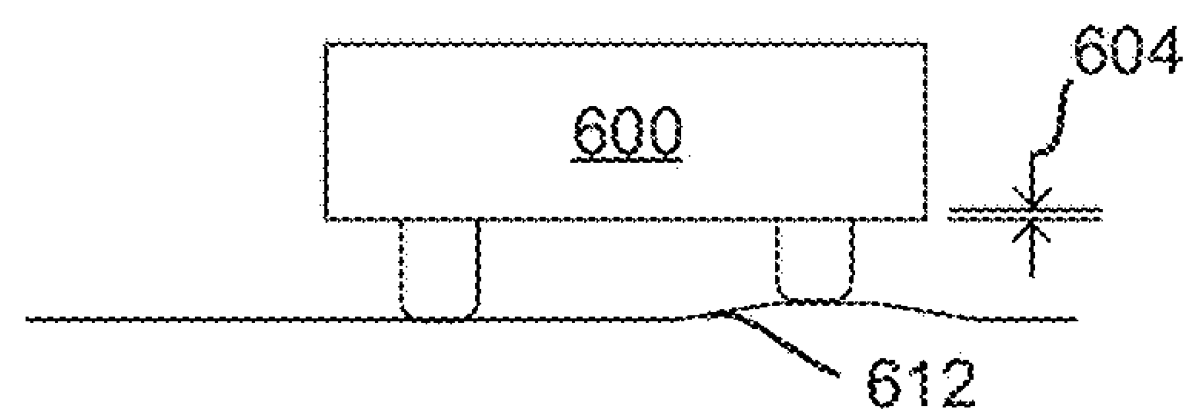


FIG. 6B

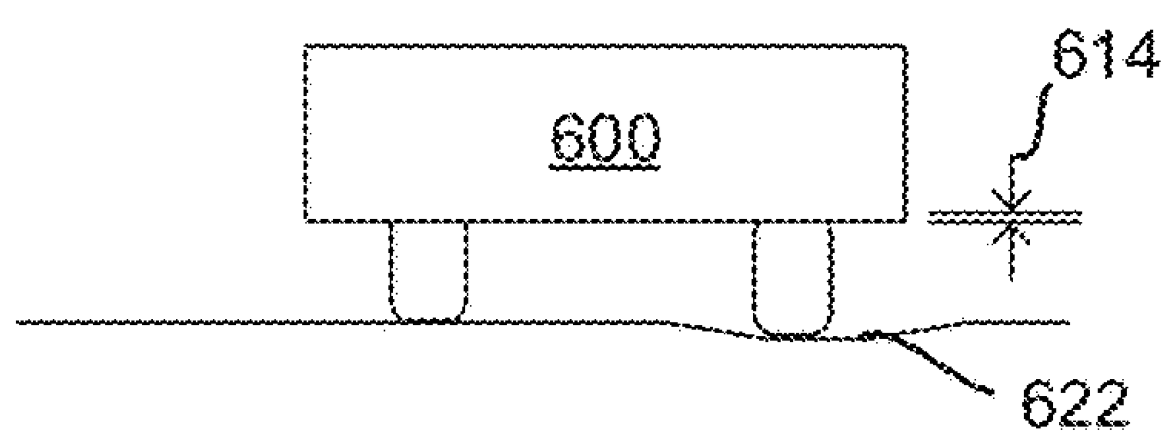


FIG. 6C

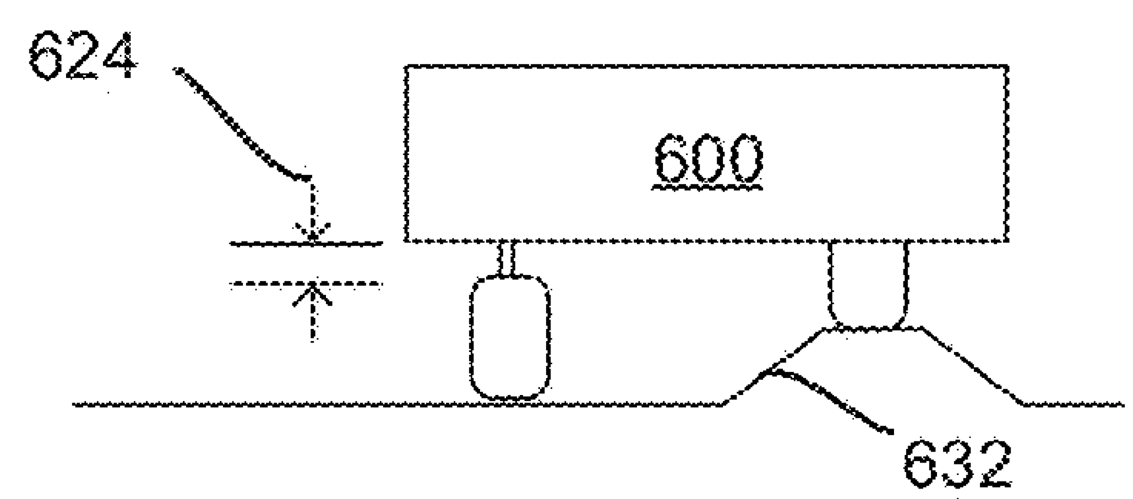


FIG. 6D

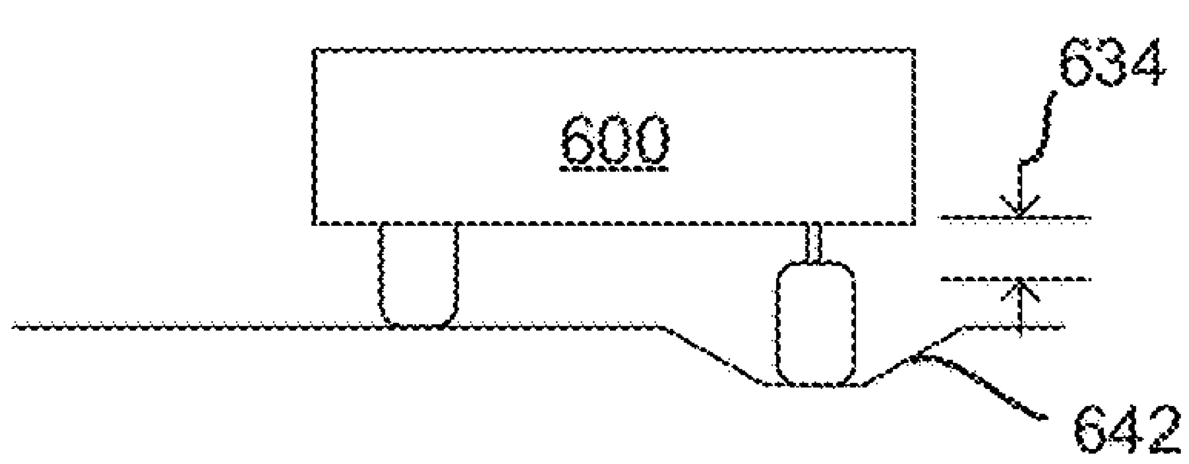


FIG. 6E

FIG. 7A

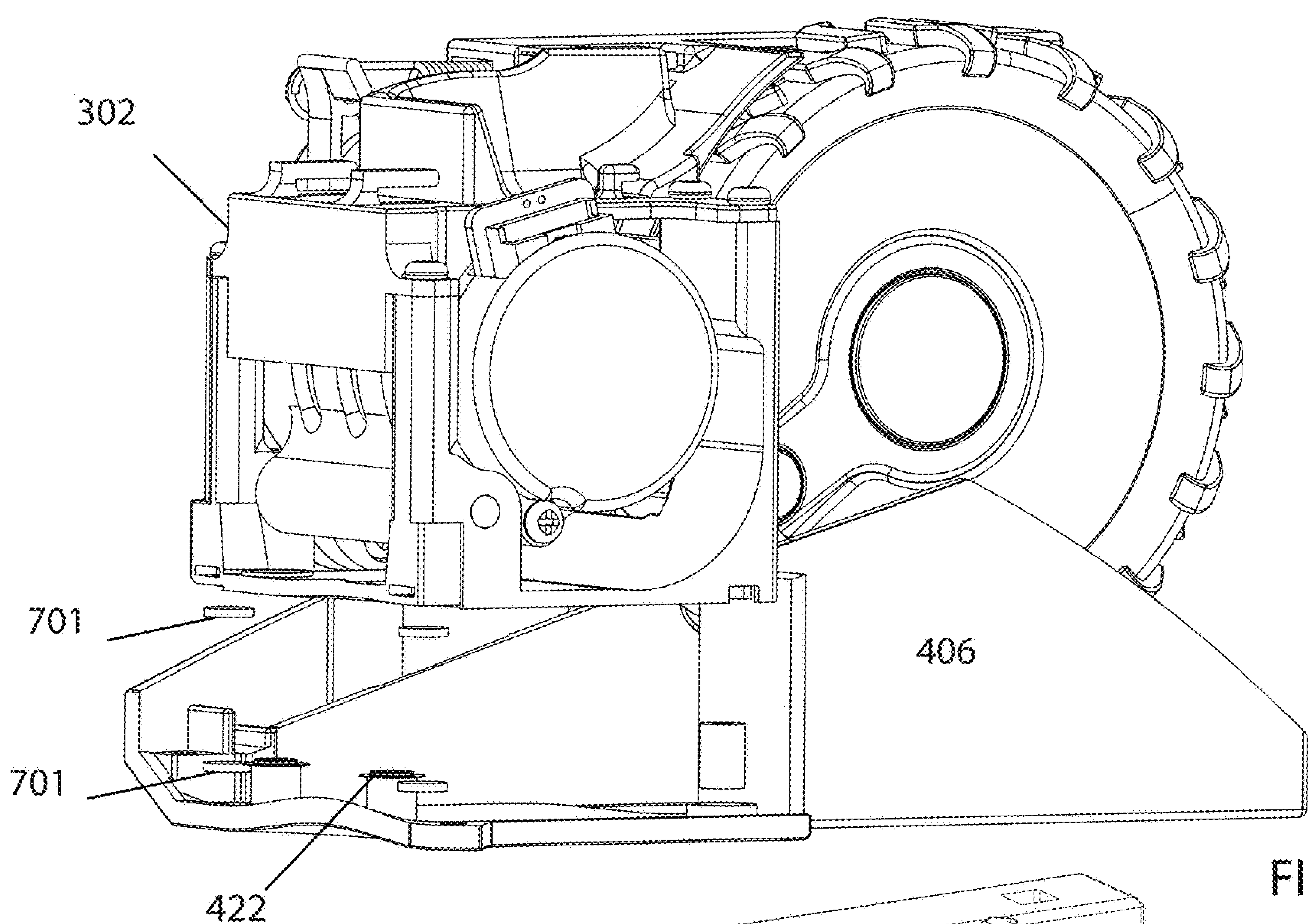


FIG. 7B

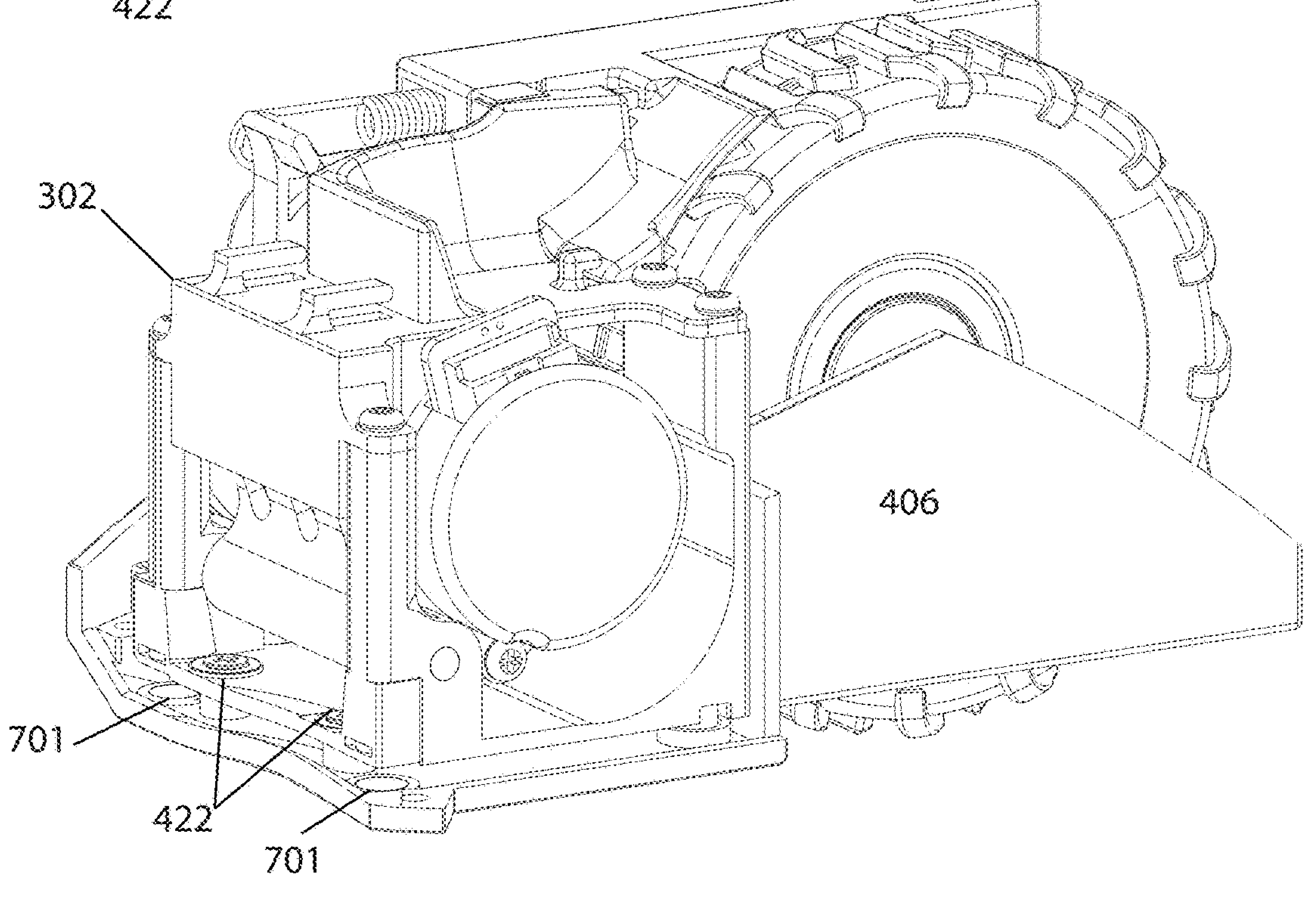
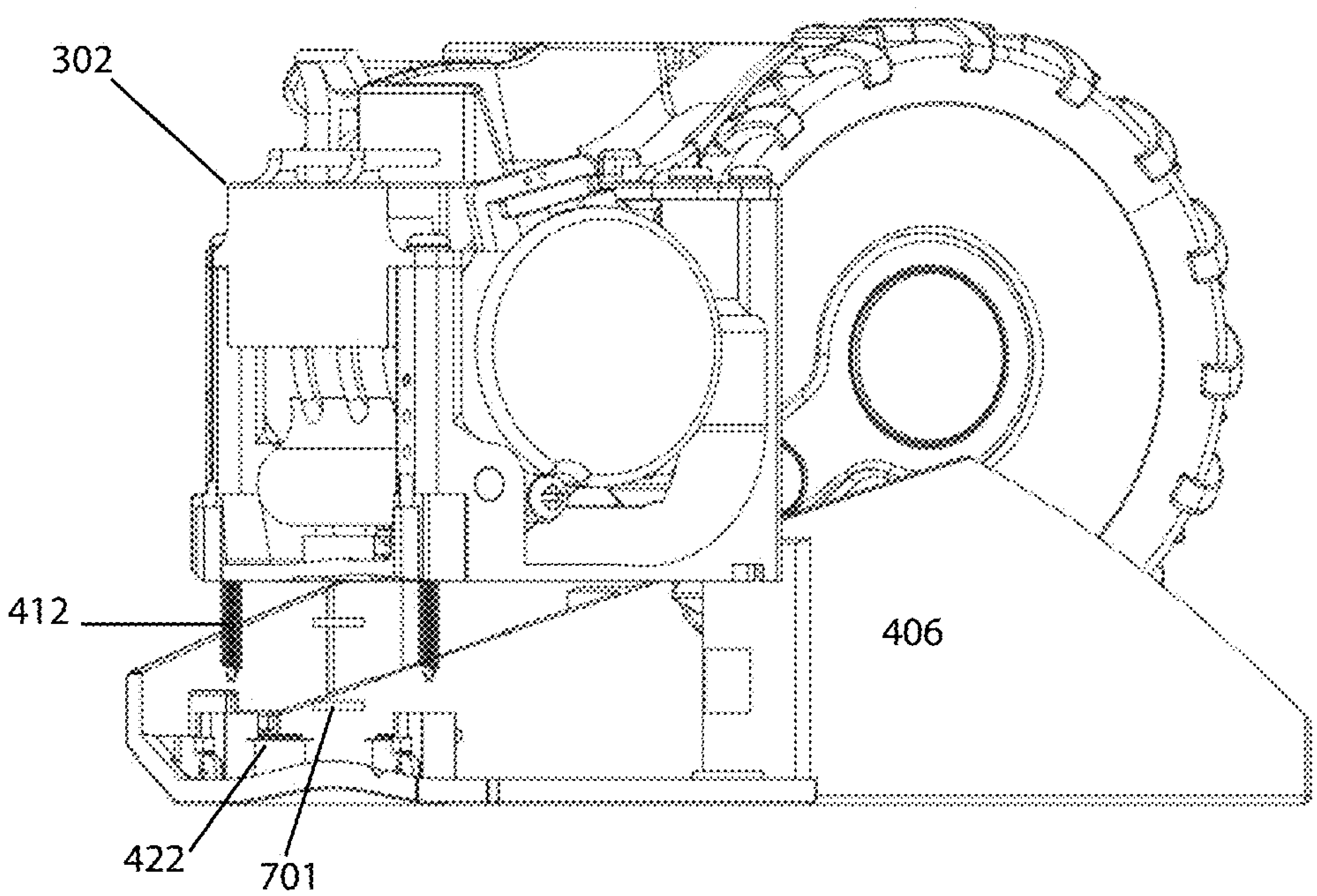


FIG. 8



WHEEL SUSPENSION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of U.S. patent application Ser. No. 15/951,096, filed Jul. 30, 2018, which is a Non-Provisional Patent Application of U.S. Provisional Patent Application Nos. 62/540,189, filed Aug. 2, 2017, 62/617,589, filed Jan. 15, 2018, and 62/620,352, filed Jan. 22, 2018, and which has a corresponding International Patent Application No. PCT/US18/44357, filed Oct. 1, 2018, all of which are herein incorporated by reference.

FIELD OF INVENTION

Present embodiments related to suspension systems for robotic devices. In particular to suspension systems in robotic vacuums.

BACKGROUND

A car requires a dynamic wheel system to achieve control and stability by maintaining contact between the wheels and the ground at all times, particularly when driving over uneven surfaces and obstacles. A robotic vacuum may also benefit from a dynamic wheel system to operate effectively as they drive in a variety of indoor environments comprising combinations of hardwood, carpeted, and tiled floors, along with rugs and doorways that form uneven surfaces and act as obstacles. Objects such as cords may also be encountered. Using a static wheel system, any obstacles or transitions, such as a door threshold, could only be overcome by supplying the wheels with large amounts of torque, which is ineffective. In a worse-case scenario, the robot may stall if its wheels lose contact with the floor.

As such, a double suspension, dynamic wheel system for robotic devices is presented herein.

SUMMARY

The following presents a simplified summary of some embodiments of the invention in order to provide a basic understanding of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some embodiments of the invention in a simplified form as a prelude to the more detailed description that is presented below.

Some aspects provide a robotic device including: a body; an electronic computing device housed within the body; and at least two wheel suspension systems coupled with the body, each wheel suspension system including: a first suspension system including: a frame; rotating arm pivotally coupled to the frame on a first end and coupled to a wheel on a second end; and an extension spring coupled with the rotating arm on a third end and the frame on a fourth end, wherein the extension spring is extended when the wheel is retracted; and a second suspension system including: a base slidingly coupled with the frame; a plurality of vertically positioned extension springs coupled with the frame on a fifth end and the base on a sixth end; at least one set of paired magnets, with at least one magnet affixed to the frame and paired to at least one magnet affixed to the base.

Some aspects provide a wheel suspension system including: a first suspension system including: a frame; a rotating arm pivotally coupled to the frame on a first end and coupled to a wheel on a second end; and an extension spring coupled with the rotating arm on a third end and the frame on a fourth end, wherein the extension spring is extended when the wheel is retracted; and a second suspension system including: a base slidingly coupled with the frame; and at least one set of paired magnets, with at least one magnet affixed to the frame and paired to at least one magnet affixed to the base.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-**1**C are prior art illustrative representations of a rolling device with static wheel system.

FIGS. **2**A-**2**C are prior art illustrative representations of a rolling device with trailing arm suspension system.

FIGS. **3**A-**3**C are illustrative representations of a wheel according to some embodiments.

FIG. **4** is an illustrative representation of a wheel according to some embodiments.

FIGS. **5**A and **5**B are illustrative representations of a wheel according to some embodiments.

FIGS. **6**A-**6**E are illustrative representations of a robotic device with linear and trailing arm suspension systems according to some embodiments.

FIGS. **7**A and **7**B are illustrative representations of a wheel according to some embodiments.

FIG. **8** is an illustrative representation of a wheel according to some embodiments.

DETAILED DESCRIPTION

The present inventions will now be described in detail with reference to a few embodiments thereof as illustrated in the accompanying drawings. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present inventions. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process steps and/or structures have not been described in detail in order to not unnecessarily obscure the present invention. Further, it should be emphasized that several inventive techniques are described, and embodiments are not limited to systems implanting all of those techniques, as various cost and engineering trade-offs may warrant systems that only afford a subset of the benefits described herein or that will be apparent to one of ordinary skill in the art.

In still other instances, specific numeric references such as “first material,” may be made. However, the specific numeric reference should not be interpreted as a literal sequential order but rather interpreted that the “first material” is different than a “second material.” Thus, the specific details set forth are merely exemplary. The specific details may be varied from and still be contemplated to be within the spirit and scope of the present disclosure. The term “coupled” is defined as meaning connected either directly to the component or indirectly to the component through another component. Further, as used herein, the terms “about,” “approximately,” or “substantially” for any numerical values or ranges indicate a suitable dimensional tolerance that allows the part or collection of components to function for its intended purpose as described herein.

The terms “certain embodiments”, “an embodiment”, “embodiment”, “embodiments”, “the embodiment”, “the embodiments”, “one or more embodiments”, “some embodiments”, and “one embodiment” mean one or more (but not all) embodiments unless expressly specified otherwise. The terms "including", "comprising", "having" and variations thereof mean "including but not limited to", unless expressly specified otherwise. The enumerated listing of items does not imply that any or all of the items are mutually exclusive, unless expressly specified otherwise. The terms "a", "an" and "the" mean "one or more", unless expressly specified otherwise.

Static wheel systems perform poorly as the wheels are susceptible to losing contact with the driving surface when uneven surfaces are encountered. For example, the four fixed wheels of an automobile maintain contact with the road when it is completely flat. However, anytime an uneven driving surface is encountered, due to, for example, a localized bump or pothole in the road, one or more of the wheels may lose contact with the road. This effect results in discomfort for riders and reduces the control and stability of the automobile, hence the importance of suspension systems. In prior art, trailing arm suspension systems have been implemented to ensure wheels maintain contact with the driving surface when discontinuities in the surface or obstacles are traversed. A trailing arm suspension system comprises an arm that is connected to the axle on one end and a pivot point on the chassis or a component fixed to the chassis on the other end. The arm is perpendicular to the axle and the pivot point is forward of the axle, resulting in a trailing arm. The pivoting action allows the wheels to maintain contact with the driving surface when traversing uneven surfaces. A downward force may be applied to the rotating arm by, for example, a spring, causing the axle and hence wheel to be pressed against the driving surface forcefully, ensuring that the wheels maintain contact with the driving surface at all times. Configuration of the trailing arm suspension may vary. The trailing arm suspension allows each wheel to move independently of the opposite wheel and the automobile.

FIGS. **1**A-**1**C are prior art illustrative representations of a rolling device with static wheel system. In particular, FIGS. **1**B and **1**C illustrate a rolling device traversing a localized bump and a pothole on a rolling surface, respectively. In FIG. **1**A, rolling device **100** is illustrated and positioned on levelled surface **102**. As rolling device **100** drives, both wheels maintain contact with surface **102** as it is flat. In FIG. **1**B rolling device **100** encounters bump **104**. As bump **104** is traversed, rolling device **100** with static wheel system is no longer levelled and both wheels lack full contact with the rolling surface. In such instances, directional control may be impacted as well as stability. Further, without suspension, traversing localized discontinuities in the surface or obstacles may result in a bumpy or uncontrollable ride. In FIG. **1**C, rolling device **100** encounters pothole **114**. As pothole **114** is traversed on surface **112**, rolling device **100** with static wheel system is no longer level and both wheel lack full contact with the rolling surface. As above, control, stability and ride quality are impacted.

FIGS. **2**A-**2**C are prior art illustrative representations of a rolling device with trailing arm suspension traversing a flat, a localized bump, and a pothole on a rolling surface. In FIG. **2**A, rolling device **200** positioned on level surface **202** is illustrated. As rolling device **200** with trailing arm suspension **206** drives on level surface **202**, the wheels are pressed against rolling surface **202** and are in a retracted position. In FIG. **2**B, rolling device **200** traversing bump **214** is illustrated. As rolling device **200** travels over bump **214** trailing arm suspension **216** of the left wheel is engaged by lowering the left wheel as rolling device **200** is lifted on the right side. This allows both wheels to maintain contact with rolling surface thereby providing control and stability for rolling device **200** while also helping maintain a levelled chassis. In FIG. **2**C, rolling device **200** traversing pothole **224** is illustrated. As rolling device **200** encounters pothole **224**, right trailing arm suspension **226** is engaged by lowering the right wheel to ensure it maintains contact with rolling surface **202**.

Some embodiments disclosed herein provide wheeled suspension systems for improving ride quality, control and stability of a robotic device, particularly when driving over different types of surfaces (e.g. hardwood, carpet, tile, etc.), uneven surfaces (e.g. transition from hardwood to carpet, elevated divider in a doorway, etc.) and obstacles (e.g. cords, remote control, etc.). In particular, embodiments include two complementary suspension systems. The first suspension system comprises a trailing arm suspension, where a wheel is coupled to a rotating arm, the rotating arm pivoting about a point on a component fixed to the chassis. To force the wheel to maintain contact with the surface, a force causing the pivoting arm to rotate downwards and be pushed against the surface is applied by an elastic element such as a spring. The forced pivoting action allows each wheel to maintain contact with the driving surface when traversing uneven surfaces or obstacles. In some embodiments, the first suspension system may provide up to approximately **40.0** mm of vertical movement.

FIGS. **3**A-C are illustrative representations of a modular wheel according to some embodiments of the first suspension system. In particular, FIG. **3**A is an orthogonal perspective of first suspension system **300**. FIG. **3**B illustrates wheel **304** in a fully retracted position, with suspension system **300** disengaged while FIG. **3**C illustrates wheel **304** in a fully extended position. Wheel **304** is mounted to rotating arm **305** and rotating arm **305** is pivotally coupled to frame **302**, pivoting about point **307**. Spring **306** is anchored to rotating arm **305** at point **308** on one end and anchored to frame **302** on the opposite end. When wheel **304** is retracted, as in FIG. **3**B, spring **306** is extended. Since spring **306** is extended in FIG. **3**B, spring **306** pulls on point **308** of rotating arm **305**, causing it to pivot about point **307**. This causes wheel **304** to be constantly pressed against the driving surface. When an uneven surface is encountered, first suspension system **300** is engaged as in FIG. **3**C to ensure the wheel maintains contact with the surface. For example, if a hole is encountered, rotating arm **305** immediately pivots downward due to the force of spring **306**, ensuring that wheel **304** maintains contact with the surface. In embodiments, the first suspension system is a long-travel suspension system. The long-travel suspension system may, for example, provide vertical travel of up to approximately 40.0 mm.

In embodiments, a second suspension system embodiment is a short-travel suspension that complements a first suspension system such as described above. A second suspension system contains at least one extension spring positioned vertically to provide linear suspension. In other embodiments, other elastic elements may be used. One end of the extension spring is anchored to the frame of the first suspension system and the other end anchored to a base of the second suspension system, the base slidingly coupled with the frame of the first suspension system. The base and frame may therefore slide relative to one another, the two pulled together by the at least one extension spring. When the wheel is vertically retracted further into the chassis, the extension spring is further extended as the frame of the first suspension system and wheel move further upwards into the chassis. When the wheel is vertically extended beyond the chassis, the extension spring is compressed as the frame of the first suspension system and wheel move further outwards beyond the chassis. In some embodiments, dampers may be positioned along the axis of the spring to dissipate energy and provide stability to the chassis. As contemplated herein, the secondary suspension is complementary to the first suspension system. The secondary suspension system mitigates the effect of the degree of unevenness of the floor surface (i.e., rate of rise and/or rate of fall of the floor surface). In some embodiments, the second suspension system may provide up to approximately 3.0 mm of vertical movement. In some embodiments, the second suspension system may only allow movement in one direction, such as upwards, thereby allowing the wheel to further retract within the chassis. In other embodiments, the second suspension system may allow movement in two directions, allowing the wheel to retract or extend as the robot traverses uneven surfaces. In embodiments where movement in two directions is possible, the spring stiffness is such that the load of the robotic device may be supported without full compression of the spring. Therefore, the suspension may be compressed further, allowing the wheel to extend downward. Embodiments provide improved control over the robotic device by maintaining continual contact between all wheels and the driving surface while also improving the levelness of the chassis. In some embodiments, each wheel may move independently of other wheels and the chassis of the robotic device.

FIG. **4** is an illustrative representation of a modular wheel **400** according to some embodiments of the second suspension system. As illustrated, frame **302** may be slidingly coupled with base **406**. In some embodiments, base **406** includes a number of mounting elements for mounting to a robotic device, such as a robotic vacuum device, for example. Mounting elements are well-known in the art and may be utilized in any form factor without limitation. As noted above, a second suspension system embodiment is a short-travel suspension that complements a first suspension system. Second suspension system embodiments are linearly actuated, providing linear action as compared with the pivoting action provided by the first suspension system. As illustrated, second suspension system includes extension springs **412** that are coupled with base **406** by lower anchors **414**. Extension springs **412** are also coupled with frame **302** by upper anchors **416**. Further, extension springs **412** are secured within spring housings **418**. As noted above, extension springs **412** are intended to be stiff enough to slightly overcome the weight of the robotic device, particularly when movement in two directions is allowed. As such, any extension spring tension may be selected to function properly for a given weight of a robotic device without departing from embodiments provided herein. Extension spring embodiments may include other elastic elements without limitation.

Further illustrated are dampers **420**, which may be positioned along the axis of extension springs **412**. Dampers are an effective compliment to springs, as springs can easily collect and eject energy when the robotic device hits a bump or dip. Dampers may be useful to disperse this energy. For example, after a robotic device clears an obstacle, there may be residual oscillating energy in the suspension springs that may cause the robotic device to oscillate and vibrate. Dampers may serve to disperse this energy, keeping the robotic device stable. However, embodiments herein do not require dampers.

Still further illustrated are travel limiting screws **422** that may be disposed on base **406**. Travel limiting screws **422** fit are coupled with frame **302** and fit within holes **432**. Travel limiting screws **422** limit the travel of frame **302** as frame **302** moves relative to base **406**. The tension of extension springs **412** may be chosen such that the position of frame **302** along the length of the shaft of travel limiting screws **422** may provide a desired range of upward and downward vertical movement. When placed on the driving surface, a force substantially equal and opposite to the weight of the robotic device acts on the wheels (**304**), thereby pushing frame **302** vertically upwards relative to base **406**. Since frame **302** and base **406** are mechanically coupled by extension springs **412**, the tension of extension springs **412** determine the amount by which frame **302** is pushed upwards. For example, when frame **302** is positioned above travel limiting screws **422**, the secondary suspension system is configured to provide upwards and downwards vertical movement. In some embodiments, movement in one direction is provided while in other embodiments movement in two directions is provided. In some embodiments, the retracted distance (maximum upward movement) is equal to the extended distance (maximum downward movement). In other embodiments, the retracted distance is greater than the extended distance and vice versa. In some embodiments, the retracted distance and the extended distance are approximately 3.0 mm. In other embodiments, other retracted distances and extended distances are possible.

For example, FIGS. **5**A and **5**B demonstrate one embodiment of the second suspension system wherein only upward vertical movement of frame **302** relative to base **406** is allowed. The chosen stiffness of springs **412** are such that the force acting on the wheels cannot cause extension of springs **412** and hence position frame **302** at a distance upwards along the shaft of travel limiting screws **422**. As such, frame **302** is positioned at the base of the shaft of travel limiting screws **422**, allowing only upward movement of frame **302** and wheel **304**. In the illustrated embodiment, the second suspension system has three points of suspension **442** wherein three extension springs and corresponding structures are utilized, making it a three-point suspension system. In other embodiments, the second suspension system may contain any other number of springs, for example, two extension springs make the system a two-point suspension system. The three-point suspension system of FIG. **5**A illustrates the position of frame **302** and attached wheel **304** when the suspension system is not engaged while FIG. **5**B illustrates the position of frame **302** and attached wheel **304** when the suspension system is engaged and at maximum retraction. In FIG. **5**A the total possible upward movement of frame **302** and attached wheel **304** is shown by distance **502**, limited by travel limiting screws **422**. FIG. **5**B shows the total vertical distance **504** by which frame **302** and wheel **304** travelled to reach maximum retraction. The illustrated representations are presented in color to more clearly illustrate the component parts of the invention as disclosed herein. In some embodiments, however, travel limiting screws may not be required.

FIGS. **6**A-**6**E are illustrative representations of a robotic device according to some embodiments of the present invention. Employment of two complementary suspension systems are illustrated. In this example, the second suspension system allows linear travel in two directions. In FIG. **6**A, robotic device **600** is positioned on level surface **602** and all wheels have full contact with flat surface **602**. In FIG. **6**B robotic device **600** encounters slight bump **612**. As robotic device **600** traverses minor bump **612** the second suspension system is engaged slightly raising the right wheel by distance **604** such that robotic device **600** may maintain a level attitude. In FIG. **6**C, robotic device **600** encounters minor pothole **622**. As robotic device **600** traverses minor pothole

622 the second suspension system is engaged slightly lowering the right wheel by distance **614** such that robotic device **600** may maintain a levelled attitude. In this manner, the second suspension engages before the first suspension and thus provides a wider range of suspension for robotic devices.

In FIG. **6**D, robotic device **600** encounters large bump **632**. As robotic device **600** traverses bump **632** the first and second suspension systems are engaged, lowering the left wheel by a total distance **624** such that the wheels of robotic device **600** maintain contact with the driving surface and the chassis remains at a levelled attitude. In FIG. **6**E, robotic device **600** encounters pothole **642**. As robotic device **600** traverses pothole **642** the first and second suspension systems are engaged to lower the right wheel by a total distance **634** such that the wheels of robotic device **600** maintain contact with the driving surface and the chassis remains at a levelled attitude. In this manner, the second suspension engages along with first suspension and thus provides a wider range of suspension for robotic devices.

An approximate range considered for the second suspension system is small when compared to the range of the first suspension system. For example, in some embodiments, the ratio of travel between the first and second suspension systems may be at least approximately 10:1. In some embodiments, the vertical movement of the first suspension is approximately 40.0 mm, for example, and the vertical movement of the second suspension is approximately 3.0 mm, for example. In particular, for the second suspension system, the wheels may move 1.5 mm up and 1.5 mm down, for a total range of approximately 3.0 mm. If the robotic device encounters a bump or dip smaller than 1.5 mm, the bump or dip may go completely unnoticed by the rest of the robotic device. In the case of a bump or dip larger than 1.5 mm, the robotic device will not remain at the same height throughout. However, the second suspension system acts as a first line of defense and may make this transition effectively smaller and more gradual. In other embodiments, other ratio of travel between the first and second suspension systems are possible and other vertical movement measurements may be achieved.

In addition to the aforementioned springs, a set of dampers may be incorporated into wheel assembly embodiments. Dampers may be an effective compliment to springs, as springs can easily collect and eject energy when the robotic device hits a bump or dip. Dampers may be useful to disperse this energy. For example, after a robotic device clears an obstacle, there may be residual oscillating energy in the suspension springs that may cause the robotic device to oscillate and vibrate. Dampers may serve to disperse this energy, keeping all motion of the robotic device stable. In some embodiments, however, dampers are not required.

In some embodiments, magnets may be used in exchange for extension springs in the second suspension system. In FIG. **7**A an exploded view is shown with inclusion of magnets **701**. FIG. **7**B illustrates the second suspension system comprising base **406**, slidingly coupled with frame **302**, the two attracted to each other by paired magnets **701**. Paired magnets are oriented by opposite poles such that they attract one another. As illustrated, one of the paired magnets **701** is affixed to frame **302** while the other paired magnet is affixed to base **406**. Traveling limiting screws **422** limit the linear separation of frame **302** and base **406** as they slide relative to one another. Upon encountering uneven surfaces, such as small bumps or holes, the magnets will separate and pull back together as required, allowing a smoother ride. One or more sets of magnets may be used between frame **302** and base **406**. For instance, two magnet pairs may be positioned in the rear with one in the front and one on the side. Other variations may also be possible. In one embodiment, each wheel will utilize three magnet pairs. In yet another embodiment, magnets may be used in addition to extension springs in the second suspension system, both having complimentary functionality as when used independently. FIG. **8**A illustrates an exploded view of the second suspension system comprising extension springs **412** and magnetic pair **701**. Extension springs **412** extend and compress and magnets come together and pull apart as the robotic device drives over uneven surfaces, providing a smoother riding experience. As above, traveling limiting screws **422** limit the linear separation of frame **302** and base **406** as they slide relative to one another.

As noted above, wheel embodiments may be utilized in combination with a robotic device such as a robotic vacuum. In use, three or more wheel embodiments may be incorporated with a robotic device, where the robotic device includes a body and an electronic computing device housed within the body. Wheel embodiments may be removably coupled with a robotic device. Wheel embodiments provide improved handling characteristics for robotic devices.

While this invention has been described in terms of several embodiments, there are alterations, permutations, and equivalents, which fall within the scope of this invention. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention. Furthermore, unless explicitly stated, any method embodiments described herein are not constrained to a particular order or sequence. Further, the Abstract is provided herein for convenience and should not be employed to construe or limit the overall invention, which is expressed in the claims. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.

The functionality provided by each of the components described herein may be provided by hardware modules that are differently organized than is presently depicted. For example, such hardware may be intermingled, conjoined, replicated, broken up, distributed (e.g. geographically), or otherwise differently organized.

The reader should appreciate that the present application describes several independently useful techniques. Rather than separating those techniques into multiple isolated patent applications, the applicant has grouped these techniques into a single document because their related subject matter lends itself to economies in the application process. But the distinct advantages and aspects of such techniques should not be conflated. In some cases, embodiments address all of the deficiencies noted herein, but it should be understood that the techniques are independently useful, and some embodiments address only a subset of such problems or offer other, unmentioned benefits that will be apparent to those of skill in the art reviewing the present disclosure. Due to costs constraints, some techniques disclosed herein may not be presently claimed and may be claimed in later filings, such as continuation applications or by amending the present claims. Similarly, due to space constraints, neither the Abstract nor the Summary of the Invention sections of the present document should be taken as containing a comprehensive listing of all such techniques or all aspects of such techniques.

It should be understood that the description and the drawings are not intended to limit the present techniques to the particular form disclosed, but to the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present techniques as defined by the appended claims. Further modifications and alternative embodiments of various aspects of the techniques will be apparent to those skilled in the art in view of this description. Accordingly, this description and the drawings are to be construed as illustrative only and are for the purpose of teaching those skilled in the art the general manner of carrying out the present techniques. It is to be understood that the forms of the present techniques shown and described herein are to be taken as examples of embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed or omitted, and certain features of the present techniques may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the present techniques. Changes may be made in the elements described herein without departing from the spirit and scope of the present techniques as described in the following claims. Headings used herein are for organizational purposes only and are not meant to be used to limit the scope of the description.

As used throughout this application, the word “may” is used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). The words “include”, “including”, and “includes” and the like mean including, but not limited to. As used throughout this application, the singular forms “a,” “an,” and “the” include plural referents unless the content explicitly indicates otherwise. Thus, for example, reference to “an element” or “a element” includes a combination of two or more elements, notwithstanding use of other terms and phrases for one or more elements, such as “one or more.” The term “or” is, unless indicated otherwise, non-exclusive, i.e., encompassing both “and” and “or.” Terms describing conditional relationships, e.g., “in response to X, Y,” “upon X, Y,”, “if X, Y,” “when X, Y,” and the like, encompass causal relationships in which the antecedent is a necessary causal condition, the antecedent is a sufficient causal condition, or the antecedent is a contributory causal condition of the consequent, e.g., “state X occurs upon condition Y obtaining” is generic to “X occurs solely upon Y” and “X occurs upon Y and Z.” Such conditional relationships are not limited to consequences that instantly follow the antecedent obtaining, as some consequences may be delayed, and in conditional statements, antecedents are connected to their consequents, e.g., the antecedent is relevant to the likelihood of the consequent occurring. Statements in which a plurality of attributes or functions are mapped to a plurality of objects (e.g., one or more processors performing steps A, B, C, and D) encompasses both all such attributes or functions being mapped to all such objects and subsets of the attributes or functions being mapped to subsets of the attributes or functions (e.g., both all processors each performing steps A-D, and a case in which processor **1** performs step A, processor **2** performs step B and part of step C, and processor **3** performs part of step C and step D), unless otherwise indicated. Further, unless otherwise indicated, statements that one value or action is “based on” another condition or value encompass both instances in which the condition or value is the sole factor and instances in which the condition or value is one factor among a plurality of factors. Unless otherwise indicated, statements that “each” instance of some collection have some property should not be read to exclude cases where some otherwise identical or similar members of a larger collection do not have the property, i.e., each does not necessarily mean each and every. Limitations as to sequence of recited steps should not be read into the claims unless explicitly specified, e.g., with explicit language like “after performing X, performing Y,” in contrast to statements that might be improperly argued to imply sequence limitations, like “performing X on items, performing Y on the X’ed items,” used for purposes of making claims more readable rather than specifying sequence. Statements referring to “at least Z of A, B, and C,” and the like (e.g., “at least Z of A, B, or C”), refer to at least Z of the listed categories (A, B, and C) and do not require at least Z units in each category. Unless specifically stated otherwise, as apparent from the discussion, it is appreciated that throughout this specification discussions utilizing terms such as “processing,” “computing,” “calculating,” “determining” or the like refer to actions or processes of a specific apparatus, such as a special purpose computer or a similar special purpose electronic processing/computing device. Features described with reference to geometric constructs, like “parallel,” “perpendicular/orthogonal,” “square”, “cylindrical,” and the like, should be construed as encompassing items that substantially embody the properties of the geometric construct, e.g., reference to “parallel” surfaces encompasses substantially parallel surfaces. The permitted range of deviation from Platonic ideals of these geometric constructs is to be determined with reference to ranges in the specification, and where such ranges are not stated, with reference to industry norms in the field of use, and where such ranges are not defined, with reference to industry norms in the field of manufacturing of the designated feature, and where such ranges are not defined, features substantially embodying a geometric construct should be construed to include those features within 15% of the defining attributes of that geometric construct. The terms “first”, “second”, “third,” “given” and so on, if used in the claims, are used to distinguish or otherwise identify, and not to show a sequential or numerical limitation.

The present techniques will be better understood with reference to the following enumerated embodiments:

1. A robotic device comprising: a body; an electronic computing device housed within the body; and at least two wheel suspension systems coupled with the body, each wheel suspension system comprising: a first suspension system comprising: a frame; a rotating arm pivotally coupled to the frame on a first end and coupled to a wheel on a second end; and an extension spring coupled with the rotating arm on a third end and the frame on a fourth end, wherein the extension spring is extended when the wheel is retracted; and a second suspension system comprising: a base slidingly coupled with the frame; a plurality of vertically positioned extension springs coupled with the frame on a fifth end and the base on a sixth end; at least one set of paired magnets, with at least one magnet affixed to the frame and paired to at least one magnet affixed to the base.

2. The robotic device of embodiment 1, wherein the extension spring of the first suspension system applies a force to the rotating arm as the extension spring compresses, causing the rotating arm to rotate outwards beyond the base towards the driving surface until the wheel coupled to the rotating arm contacts and presses against the driving surface.

3. The robotic device of embodiments 1-2, wherein the plurality of extension springs of the second suspension system apply a force to the frame and base, pulling the two components together as the extension springs compress.

4. The robotic device of embodiments 1-3, wherein extension of the plurality of extension springs of the second suspension system causes vertical upward movement of the frame, rotating arm, and wheel.

5. The robotic device of embodiments 1-4, wherein compression of the plurality of extension springs of the second suspension system causes vertical downward movement of the frame, rotating arm, and wheel.

6. The robotic device of embodiments 1-5, wherein the frame comprises a plurality of spring housings for retaining the plurality of extension springs of the second suspension system.

7. The robotic device of embodiments 1-6, wherein the base further comprises a plurality of travel limiting screws that limit linear displacement of the second suspension system by physically limiting the movement of the frame by contact with the screw.

8. The robotic device of embodiments 1-7, wherein the second suspension system comprises a three-point suspension system.

9. The robotic device of embodiments 1-8, wherein the at least one set of paired magnets enable the frame and base to separate when traversing uneven surfaces and pull the frame and base together after separation.

10. The robotic device of embodiments 1-9, further comprising a plurality of mounting elements that couple the double suspension wheel system to the robotic device.

11. The robotic device of embodiments 1-10, wherein the first suspension system is a long-travel suspension system.

12. The robotic device of embodiments 1-11, wherein the first suspension system is pivotally actuated.

13. The robotic device of embodiments 1-12, wherein the second suspension system is a short-travel suspension system.

14. The robotic device of embodiments 1-13, wherein the second suspension system is linearly actuated.

15. A wheel suspension system comprising: a first suspension system comprising: a frame; a rotating arm pivotally coupled to the frame on a first end and coupled to a wheel on a second end; and an extension spring coupled with the rotating arm on a third end and the frame on a fourth end, wherein the extension spring is extended when the wheel is retracted; and a second suspension system comprising: a base slidingly coupled with the frame; and at least one set of paired magnets, with at least one magnet affixed to the frame and paired to at least one magnet affixed to the base.

16. The wheel suspension system of embodiment 15, wherein the extension spring of the first suspension system applies a force to the rotating arm as the extension spring compresses, causing the rotating arm to rotate outwards beyond the base towards the driving surface until the wheel coupled to the rotating arm contacts and presses against the driving surface.

17. The wheel suspension system of embodiments 15-16, wherein the second suspension system further comprises a plurality of vertically positioned extension springs coupled with the frame on a fifth end and the base on a sixth end and wherein extension of the plurality of extension springs of the second suspension system causes vertical upward movement of the frame, rotating arm, and wheel.

18. The wheel suspension system of embodiment 17, wherein compression of the plurality of extension springs of the second suspension system causes vertical downward movement of the frame, rotating arm, and wheel.

19. The wheel suspension system of embodiment 17, wherein the frame comprises a plurality of spring housings for retaining the plurality of extension springs of the second suspension system.

20. The wheel suspension system of embodiments 15-19, wherein the base further comprises a plurality of travel limiting screws that limit linear displacement of the second suspension system by physically limiting the movement of the frame by contact with the travel limiting screws.

21. The wheel suspension system of embodiments 15-20, wherein the second suspension system comprises a three-point suspension system.

22. The wheel suspension system of embodiments 15-21, further comprising a plurality of mounting elements that couple the double suspension wheel system to a robotic device.

23. The wheel suspension system of embodiments 15-22, wherein the first suspension system is pivotally actuated and the second suspension system is linearly actuated.

24. The wheel suspension system of embodiments 15-23, wherein the first suspension system is a long-travel suspension system.

25. The wheel suspension system of embodiments 15-24, wherein the second suspension system is a short-travel suspension system.

26. The wheel suspension system of embodiments 15-25, wherein the extension spring and rotating arm of the first suspension system are horizontally oriented.

27. The wheel suspension system of embodiments 15-26, wherein the at least one set of paired magnets enable the frame and base to separate when traversing uneven surfaces and pull the frame and base together after separation.

28. The wheel suspension system of embodiment 17, wherein the second suspension system further comprises a plurality of dampers positioned along each axis of each of the plurality of extension springs of the second suspension system.

The invention claimed is:

1. A robotic device comprising:
- a body;
- an electronic computing device housed within the body; and
- at least two wheel suspension systems coupled with the body, each wheel suspension system comprising:
  - a first suspension system comprising:
    - a frame;
    - a rotating arm pivotally coupled to the frame on a first end and coupled to a wheel on a second end; and
    - an extension spring coupled with the rotating arm on a third end and the frame on a fourth end, wherein the extension spring is extended when the wheel is retracted; and
  - a second suspension system comprising:
    - a base slidingly coupled with the frame;
    - a plurality of vertically positioned extension springs coupled with the frame on a fifth end and the base on a sixth end;
    - at least one set of paired magnets, with at least one magnet affixed to the frame and paired to at least one magnet affixed to the base.

2. The robotic device of claim **1**, wherein the extension spring of the first suspension system applies a force to the rotating arm as the extension spring compresses, causing the rotating arm to rotate outwards beyond the base towards the driving surface until the wheel coupled to the rotating arm contacts and presses against the driving surface.

3. The robotic device of claim **1**, wherein the plurality of extension springs of the second suspension system apply a force to the frame and base, pulling the two components together as the extension springs compress.

4. The robotic device of claim 1, wherein extension of the plurality of extension springs of the second suspension system causes vertical upward movement of the frame, rotating arm, and wheel.

5. The robotic device of claim 1, wherein compression of the plurality of extension springs of the second suspension system causes vertical downward movement of the frame, rotating arm, and wheel.

6. The robotic device of claim 1, wherein the frame comprises a plurality of spring housings for retaining the plurality of extension springs of the second suspension system.

7. The robotic device of claim 1, wherein the base further comprises a plurality of travel limiting screws that limit linear displacement of the second suspension system by physically limiting the movement of the frame by contact with the screw.

8. The robotic device of claim 1, wherein the second suspension system comprises a three-point suspension system.

9. The robotic device of claim 1, wherein the at least one set of paired magnets enable the frame and base to separate when traversing uneven surfaces and pull the frame and base together after separation.

10. The robotic device of claim 1, further comprising a plurality of mounting elements that couple the double suspension wheel system to the robotic device.

11. The robotic device of claim 1, wherein the first suspension system is a long-travel suspension system.

12. The robotic device of claim 1, wherein the first suspension system is pivotally actuated.

13. The robotic device of claim 1, wherein the second suspension system is a short-travel suspension system.

14. The robotic device of claim 1, wherein the second suspension system is linearly actuated.

15. A wheel suspension system comprising:

a first suspension system comprising:

a frame;

a rotating arm pivotally coupled to the frame on a first end and coupled to a wheel on a second end; and

an extension spring coupled with the rotating arm on a third end and the frame on a fourth end, wherein the extension spring is extended when the wheel is retracted; and

a second suspension system comprising:

a base slidingly coupled with the frame; and

at least one set of paired magnets, with at least one magnet affixed to the frame and paired to at least one magnet affixed to the base.

16. The wheel suspension system of claim 15, wherein the extension spring of the first suspension system applies a force to the rotating arm as the extension spring compresses, causing the rotating arm to rotate outwards beyond the base towards the driving surface until the wheel coupled to the rotating arm contacts and presses against the driving surface.

17. The wheel suspension system of claim 15, wherein the second suspension system further comprises a plurality of vertically positioned extension springs coupled with the frame on a fifth end and the base on a sixth end and wherein extension of the plurality of extension springs of the second suspension system causes vertical upward movement of the frame, rotating arm, and wheel.

18. The wheel suspension system of claim 17, wherein compression of the plurality of extension springs of the second suspension system causes vertical downward movement of the frame, rotating arm, and wheel.

19. The wheel suspension system of claim 17, wherein the frame comprises a plurality of spring housings for retaining the plurality of extension springs of the second suspension system.

20. The wheel suspension system of claim 17, wherein the second suspension system further comprises a plurality of dampers positioned along each axis of each of the plurality of extension springs of the second suspension system.

21. The wheel suspension system of claim 15, wherein the base further comprises a plurality of travel limiting screws that limit linear displacement of the second suspension system by physically limiting the movement of the frame by contact with the travel limiting screws.

22. The wheel suspension system of claim 15, wherein the second suspension system comprises a three-point suspension system.

23. The wheel suspension system of claim 15, further comprising a plurality of mounting elements that couple the double suspension wheel system to a robotic device.

24. The wheel suspension system of claim 15, wherein the first suspension system is pivotally actuated and the second suspension system is linearly actuated.

25. The wheel suspension system of claim 15, wherein the first suspension system is a long-travel suspension system.

26. The wheel suspension system of claim 15, wherein the second suspension system is a short-travel suspension system.

27. The wheel suspension system of claim 15, wherein the extension spring and rotating arm of the first suspension system are horizontally oriented.

28. The wheel suspension system of claim 15, wherein the at least one set of paired magnets enable the frame and base to separate when traversing uneven surfaces and pull the frame and base together after separation.

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